Genetic Algorithms approach for containership fleet management dependent on cargo and their deadlines

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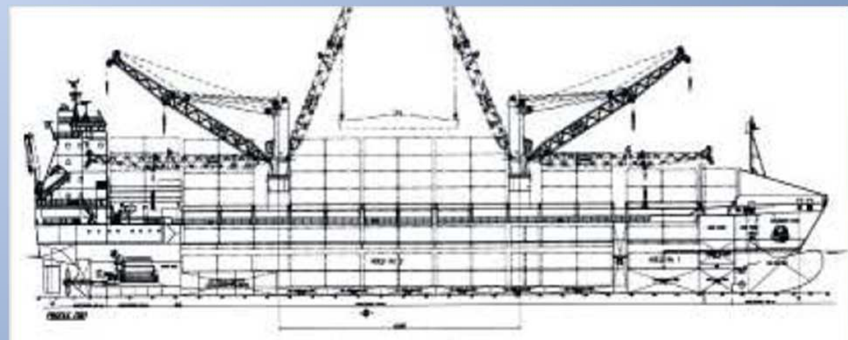

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Short Sea Shipping

Advantages

- Environmentally sound;
- Contribution to road safety;
- Low infrastructures cost (motorway is the sea);
- Reaches “peripheral” regions.

Disadvantages

- Customs bureaucracy;
- Port costs and efficiency;
- Dependency of environmental factors
- Travel duration;
- Inflexibility of routes.

State of the art - optimization

- Container stowage problem (CSP)
  - ✓ Avriel *et al*. – binary programming (1993)
    – suspensory heuristics (2000)
  - ✓ Wilson and Roach – two phase method (1999)
    – branch and bound application (2000)
  - ✓ Several authors – different implementation methods

- Ship routing and Scheduling
  - ✓ Christiansen and Nygreen (1998)
  - ✓ Agarwal and Ergun (2008)

- Vehicle routing problem with time windows - supply chains
  - ✓ Gendrau et al. (2006)
  - ✓ Moura and Oliveira (2009)

Problem definition (1)

Scenario definition:

- Five ports A , B , C , D, E
- Distances between ports < 1000 nm - *10 possible arcs*
- Fleet of Two containerships

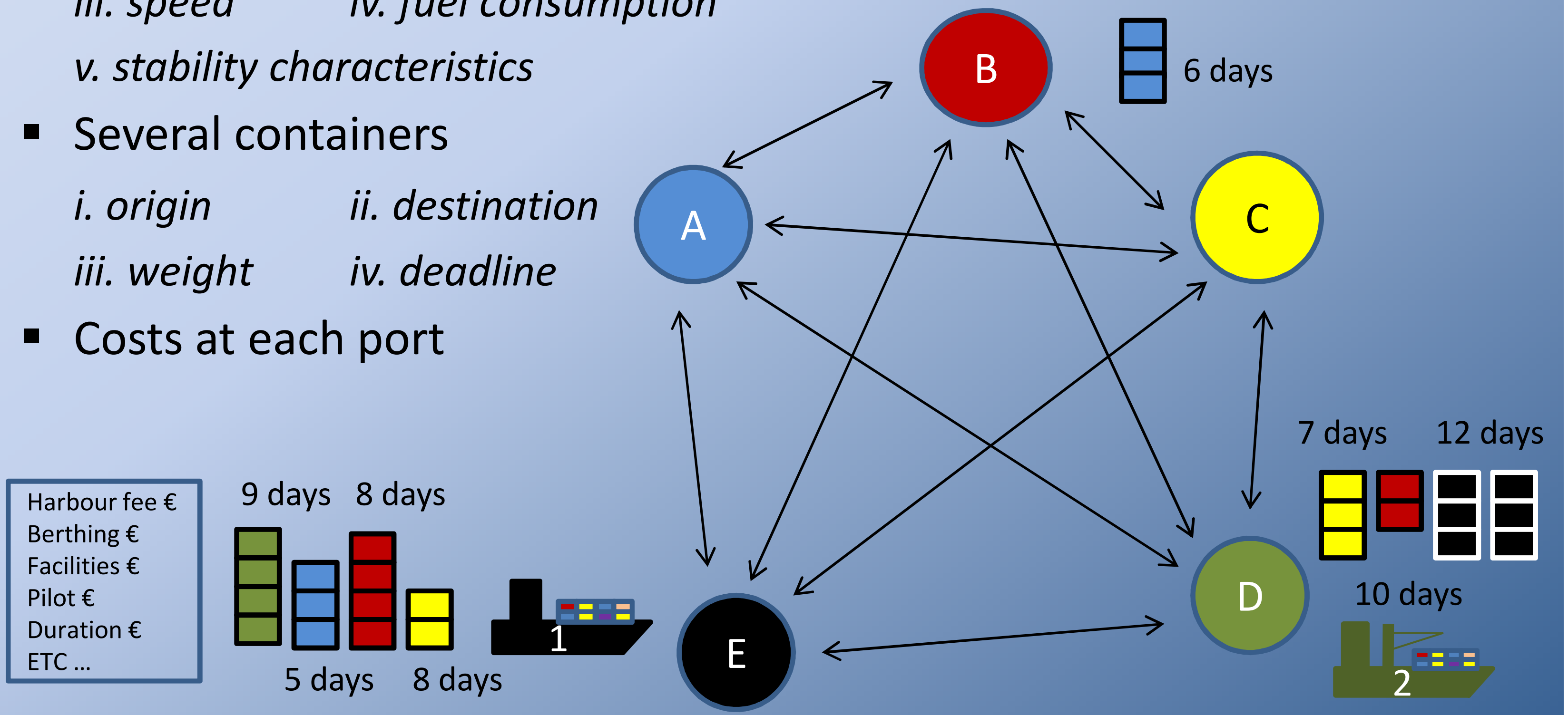
  i. dimensions *ii. deadweight*

  iii. speed *iv. fuel consumption*

  v. stability characteristics
- Several containers

  i. origin *ii. destination*

  iii. weight *iv. deadline*
- Costs at each port



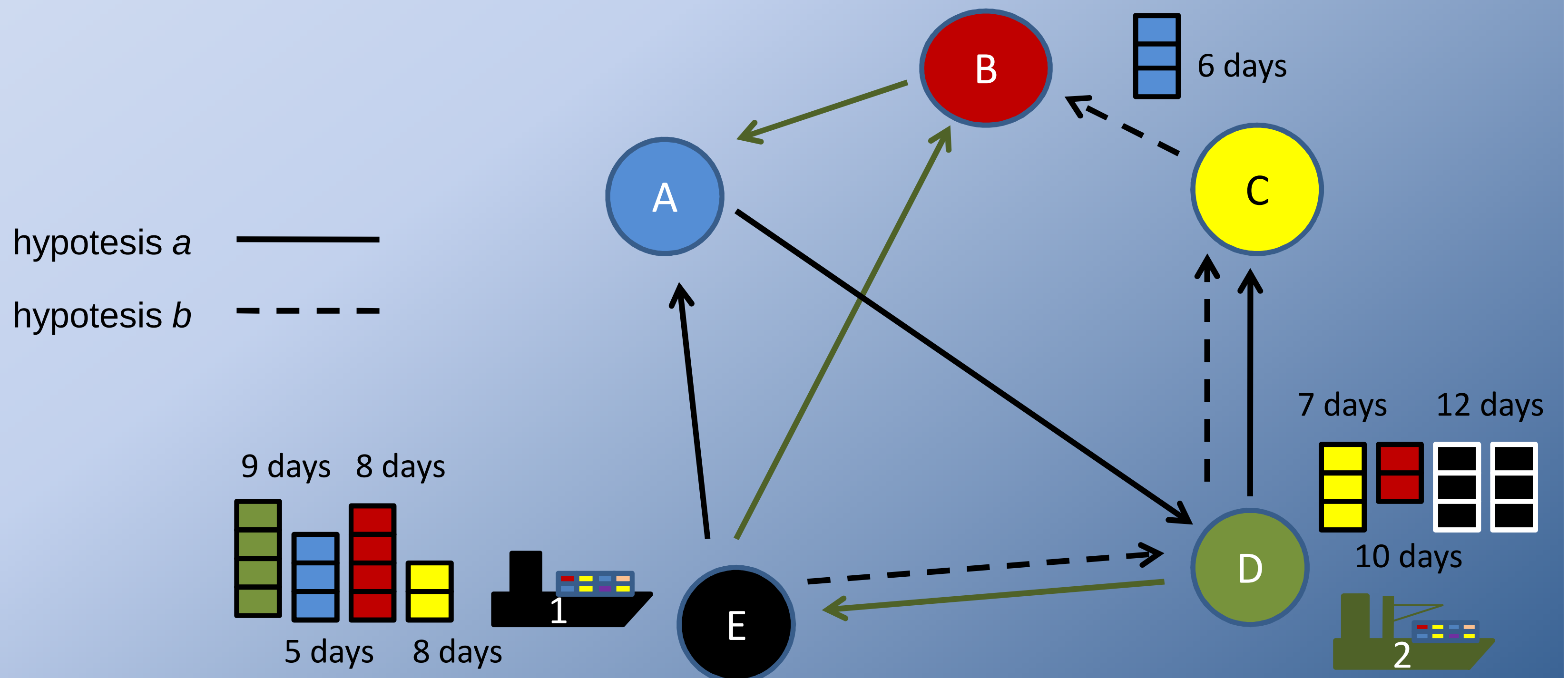
Problem definition (2)

Stage 1

- Containers characteristics and deadlines
- Containership characteristics
- Containership operation cost

What **route for each ship?**

What **containers to carry?**

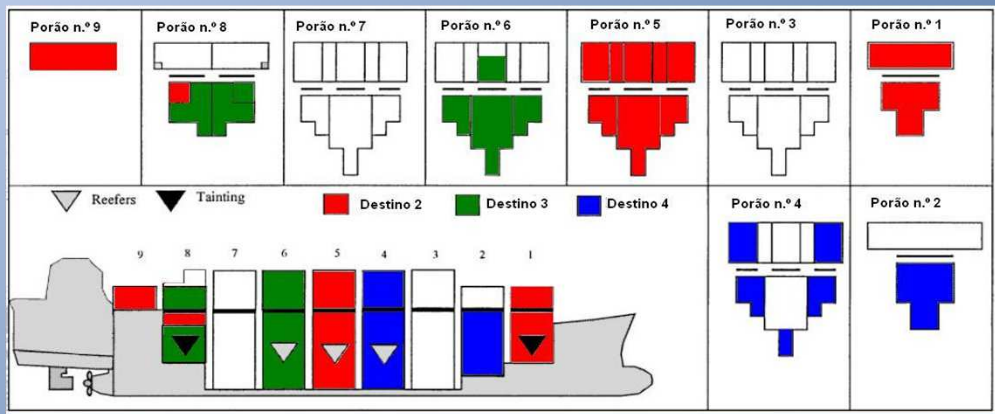


Problem definition (3)

Stage 2

- Containers characteristics and deadlines
- Containership characteristics
- Containership operation cost
- Containerships routes
- Containers carried in each journey

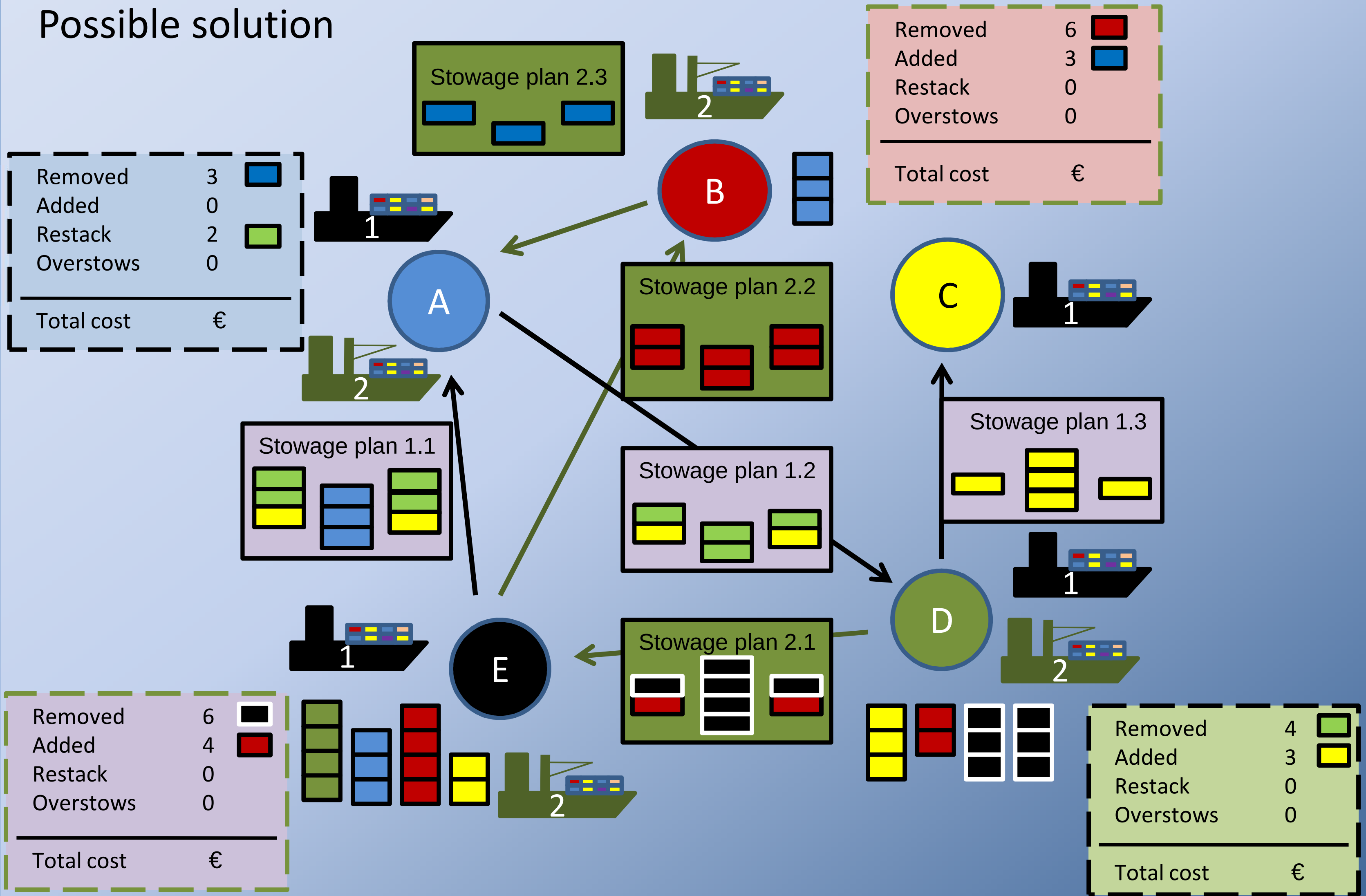
How to stow the containers



Altered from Wilson and Roach (1999)

Problem definition (4)

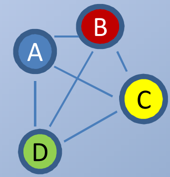
Possible solution



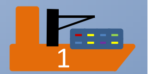
Mathematical formulation (1)

Input variables

- Ports and Scenario characteristics
- Vessels characteristics
- Containers characteristics
- Associated costs (money and time)



- distances;
- port fees;
- time to move each container



- dimensions
- fuel consumption;
- speed;
- slots arrangement;
- operation costs;

- weight
- origin;
- destination;
- dimensions;
- delivery deadline;

Decision variables

very large binary matrices

- Route selection
  - for each vessel
  - at each journey
  - what's the port of origin
  - what's the port of destination
- Container distribution and stowage
  - for each container
  - what vessel carries it
  - where is it embarked
  - what journeys is it onboard
  - where is it stowed

Mathematical formulation (2)

Objective function :

- minimize cost; AM6
- deliver all cargo within the time limits (accepted loss?) AM5

$$W_1 \sum_{i=1}^{p} \sum_{j=1 \wedge j \neq i}^{p} \sum_{k=1}^{v} \sum_{\phi=1}^{\phi_{\max}} (d_{ij} c_k x_{ijk\phi} + x_{ijk\phi} f_i)$$

Operation costs outside harbour

$$W_2 \sum_{i=1}^{p} \sum_{k=1}^{v} \sum_{\phi=1}^{\phi_{\max}} \beta_{ik\phi} \mu_{ik\phi}$$

Containers shift costs

$$W_3 \sum_{i=1}^{p} \sum_{j=1 \wedge j \neq i}^{p} \sum_{k=1}^{v} \sum_{\phi=1}^{\phi_{\max}} \sum_{\alpha=1}^{c} (Corig_{ik\phi} r_{jk\alpha\phi} + Cdest_{jk\phi} r_{ik\alpha\phi})$$

Containers load/ unload costs at the ports of origin and destination

Diapositivo 10

AM5 Para retirar
Ana Moura; 25-06-2010

AM6 - Total cost minimization;

Objective function composed of three componentes
Ana Moura; 25-06-2010

Mathematical formulation (3)

Constraints:

AM3

- route flow conservation - at each journey the vessel's port of origin is the previous port of destination;

AM2

- time sequence – the vessel service at each port does not begin before she arrives there;
- containers' deadline;
- vessel's capacity limit;

AM4

- containers' exclusivity – only one ship can carry each container at the same time;
- cargo attribution – the vessel that carries a container has to visit its port of destination (simplification);
- slots occupation – if a slot is occupied than the ones bellow are also occupied (cargo hatches not considered).

Diapositivo 11

AM2 at each port, the time service does not begins untill the vessel arrives
Ana Moura; 25-06-2010

AM3 if a vessel arrives at a node then it has to leave from that node to another one.
Ana Moura; 25-06-2010

AM4 Each container is transported by one and only one vessel between ports.
Ana Moura; 25-06-2010

Genetic Algorithms Implementation

- Formulation of the problem into two different stages:
  - a. Port sequence;
  - b. Containers distribution by vessel;
  - c. Container stowage problem.

(a, b) 1st stage implemented

(c) 2nd stage not yet implemented

- First stage chromosome construction:

Port

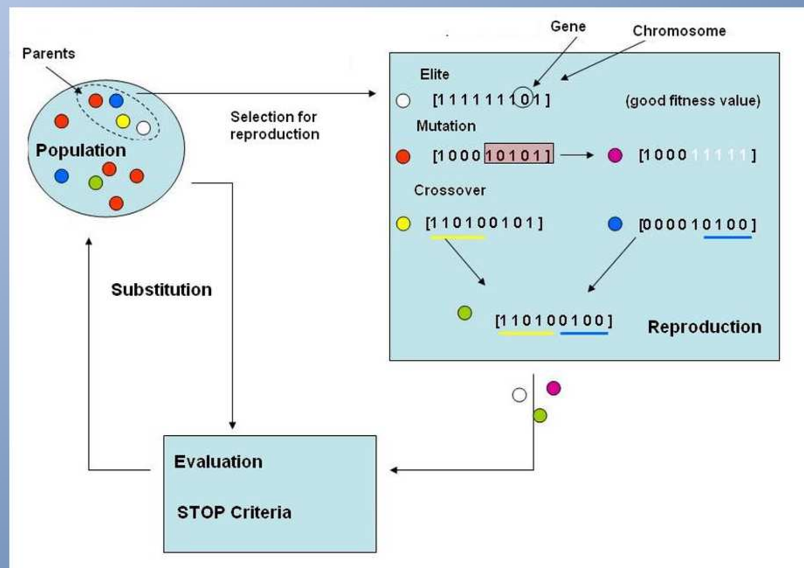
[1 2 3 4 5 0 0 0 0 3 4 5 1 2 0 0 0 ....]

Space to consider port repetition

Route for vessel 1 — Route for vessel 2

- Matlab and University of Aveiro Operators used

Biological evolution



Implementation Results

Example – scenario

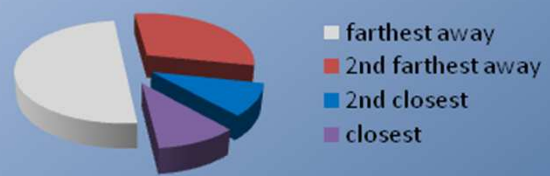
Scenario definition:

- Five ports A , B , C , D, E
- Fleet of Two containerships
- Several containers
- Operation costs and port fees

Ships	Length (m)	Beam (m)	Draught (m)	Speed (knots)	N.º TEU	Gross tonnage	Fuel (t/h)
AXE	95	15.6	6.15	12.5	348	3814	0.378
HEAVY	132.2	20	7.7	16.5	641	8445	0.945

Port tarifs (ship related costs)	Containers related costs	Voyage costs
• pilot charges; • berthing; • space; • tugs and towing;	• port tariff p/ TEU; • container embarkation; • container disembarkation; • container shift;	• fuel; • crew related;

Container's Port of destination



Container's deadlines

Container's weight

Example – Problem 1

MatLab Implementation:

- Each square stands for 50 containers
- No shift nor stowage constraints considered
- *Heavy* departs from C and *Axe* departs from A
- After 1 circular route – 100 not delivered
- After 9 ports following a circular route – 300h, all delivered but 9 deadlines were surpassed
- After 9 ports following a GA route – 271h, all delivered but 32 not in time, 5% cost reduction

Containers distribution: **A – 200** **B – 100** **C – 200** **D – 100** **E – 100**

	Ship	Route	Travelled miles	Time interval	Deadlines surpassed	Total cost
Circular routes	Axe	A – B – C – D – E	100 containers not delivered			
	Heavy	C – D – E – A – B				
	Axe	A – B – C – D – E – A – B – C – D	3372	300 h	9	469500
	Heavy	C – D – E – A – B – C – D – E – A	3164	232 h		
GA	Axe	A – B – E – D – B – A – B – E – D	3083	271 h	32	446060
	Heavy	C – D – B – A – E – B – D – C	2693	209 h		

Example – Problem 2

MatLab Implementation:

- Each square stands for 100 containers
- No shift nor stowage constraints considered
- *Heavy* departs from C and *Axe* departs from A
- After 1 circular route – no solution was found
- After 9 ports following a circular route – 100 containers not delivered
- After 9 ports following a GA route – 315.5h, all delivered but 68 not in time

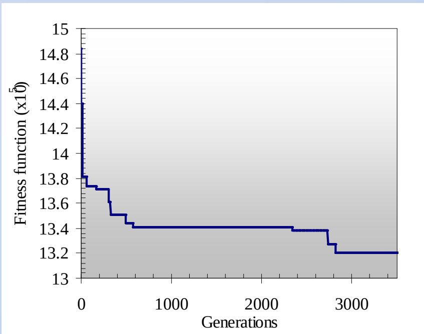
Containers distribution: **A – 400** **B – 200** **C – 400** **D – 200** **E – 200**

	Ship	Route	Travelled miles	Time interval	Deadlines surpassed	Total cost
Circular routes	Axe	A – B – C – D – E	Not every container was embarked			
	Heavy	C – D – E – A – B				
	Axe	A – B – C – D – E – A – B – C – D	100 containers not delivered			
	Heavy	C – D – E – A – B – C – D – E – A				
GA	Axe	A – B – D – E – B – A – B – D – E	3134	315.5 h	68	634960
	Heavy	C – B – A – B – E – B – D – C	2653	236 h		

Example – Problem 3

University of Aveiro software:

- No shift, deadlines, nor stowage constraints considered
- *Heavy* departs from C and *Axe* departs from A;
- Following a circular route it was found that 15 ports had to be visited by each ship
- Two solutions better were found, with cost reductions of 7% and 14%



Container distribution:	from/to	A	B	C	D	E
	A	0	100	500	300	100
	B	250	0	150	50	50
	C	500	100	0	100	500
	D	250	50	50	0	150
	E	250	50	150	50	0

	Ship	Route	Travelled miles	Time interval	Deadlines surpassed	Total cost
Pre-defined	Axe	A - B - C - D - E - A - B - C - D - E - A - B - C - D - E	6536	637.3 h	-	566039.1
	Heavy	C - D - E - A - B - C - D - E - A - B - C - D - E - A	6844	620.3 h	-	958090.1
	Axe	A - B - E - D - A - B - E - C - A - D	5437	561.7 h	-	551051.4
	Heavy	C - D - B - A - E - D - C - A - C	4367	527.6 h	-	871738.4
GA	Axe	A - C - A - B - E - D - C - B	3831	435.2 h	-	481087.7
	Heavy	C - A - B - C - D - C - E - B - A	3657	451.8 h	-	833674.2

Conclusions

- Conceptual and mathematical models have been built for the containership fleet management considering cargo deadlines, which included:
  - ✓ Route selection;
  - ✓ Cargo distribution per ship;
  - ✓ Container stowage problem solution.
- A Genetic algorithm implementation for route selection and cargo distribution has been done;
- Using a simple scenario of 2 containerships and 5 ports with distances between them smaller than 1000 nm, it was seen that:
  - ✓ There are routes better than circular pattern ones;
  - ✓ It is possible to manage a fleet considering the cargo deadlines and reducing time duration when necessary;
  - ✓ It is possible to turn the maritime transport more flexible with cost reductions.

Future development

- Mathematical model improvement
- Implementation of the CSP in the GA model
- Analysis of different methods efficiency to solve the model other than GA
- Analysis of real scenarios with real data (collaboration required)
- Analysis of the impact of vessel characteristics in the results
- Use the model to define owner requirements for new ship constructions based on known scenarios